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STUDY OF THIN FILM LARGE AREA  
PHOTOVOLTAIC SOLAR ENERGY CONVERTER

Third Monthly Status Report  
January 1, 1963 through January 31, 1963

Contract No. NAS7-203

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By W J Deshotelis

F Augustine

Clevite Corporation  
ELECTRONIC RESEARCH DIVISION  
Cleveland, Ohio

# STUDY OF THIN FILM LARGE AREA PHOTOVOLTAIC SOLAR ENERGY CONVERTER

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## 1. PRODUCTION OF FILMS

Experiments on evaporator and substrate parameters are continuing. One of the best evaporator arrangements devised so far is the four crucible evaporator, described in the First Quarterly Report<sup>(1)</sup>, consisting of four large alundum or porcelain crucibles supported in a framework of stainless steel. It has not been necessary to use nesting crucibles as in earlier configurations. Each crucible contains a tantalum coil heater in contact with the charge.

CdS films have been evaporated on eight 1" x 1" H film substrates and two 4" x 4" glass substrates during the past month. Several were destroyed during subsequent processing, mostly by peeling off the substrate while in the electroplating bath. Others peeled or flaked off during the heat treatment or after coating with cuprous oxide slurry. The films evaporated on glass substrates were more adherent, but one also loosened in the plating bath. These evaporations were performed in the new vacuum system. It is believed that the poor adherence is due to an excess of indium dopant in the charge or perhaps to a change in one or more of the system parameters, e.g., charge to substrate distance (greater than before) or temperature gradients in the neighborhood of the substrate due to the larger substrate heater. These difficulties are being studied and should be resolved in the near future. In the new vacuum system, four 4" x 4" substrates may be coated simultaneously whereas only one such substrate could be accommodated in the old vacuum system.

## 2. PROCESSING OF FILMS

The film failure in the plating bath caused renewed interest in mechanically applying cuprous oxide<sup>(1)</sup> to CdS films. This process was described in the First Quarterly Report and it was noted that spraying the cuprous oxide resulted in a relatively weak photovoltaic effect. The process has been greatly improved and consists, now, of painting the CdS film with a slurry of cuprous oxide. The

(1) W. J. Deshotelis and F. Augustine, "Study of Thin Film Large Area Photovoltaic Solar Energy Converter," First Quarterly Report, January 11, 1963, Contract No. NAS7-203.

optimum heat treatment has not yet been determined in detail but photovoltaic cells are now produced with much shorter heating times than required by electroplated cuprous oxide barrier layers. The excess cuprous oxide is brushed off after the heat treatment and the cell is electroded with air drying silver paint.

### 3. PRODUCTION OF CELLS

CdS photovoltaic cells processed by the above technique were produced in both film and crystal form. Figure 1 shows the volt-ampere characteristic for a single crystal CdS cell having an efficiency of 5.47 percent<sup>\*</sup> and Figure 2 for a single crystal cell with an efficiency of 7.02 percent. This is as high as has been obtained from single crystal cells processed conventionally, i.e., electroplated with cuprous oxide and heated for relatively long times. Therefore, one may conclude these two processes of forming the cuprous oxide barrier layer are equivalent. The situation with film cells is not as good although steady improvement has been made. Figure 3 shows the volt-ampere characteristic for one of the first film cells processed with a slurry of cuprous oxide. This cell had an efficiency of 0.086 percent over an area of 41 cm<sup>2</sup>. This film could not have been processed by the electrolytic method of Cu<sub>2</sub>O deposition because of its high resistance of 25 ohms per square. This high resistance also accounts in great part for the low efficiency.

A cell on H-film made by brush coating the copper oxide slurry remained intact and adherent. The volt-ampere characteristic of this cell is shown in Figure 4. The efficiency is 0.67 percent. The characteristic of a cell similarly made on glass is shown in Figure 5. The efficiency is 0.9 percent. It is anticipated that higher efficiencies will be obtained after further experimentation with doping level and heat treatment. One very encouraging fact to be noted is the relatively large areas of the cells of Figures 3, 4, and 5, especially that of Figure 3. A conventionally prepared film cell is shown in Figure 6. This cell has an efficiency of 3.23 percent over an area of 0.44 cm<sup>2</sup>. It was prepared from a film evaporated prior to the start of the present contract.

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<sup>\*</sup>The absolute accuracy achieved in cell efficiency measurements is probably no better than  $\pm 20\%$  because it is not yet known how closely the artificial light source approximates solar radiation. The relative probable error in any given sequence of efficiency measurements is less than  $\pm 2\%$ .

#### 4. OPTICAL MEASUREMENTS

Spectral transmission measurements are obtained by the sample-in-sample-out technique using a Bausch & Lomb grating monochromator having a 500 mm focal length and a 10 x 10 cm, 600 groove/mm grating blazed at 5000 Å in the first order. Dispersion of the instrument is 33 Å per mm in the first order. The range of the instrument is 0.2 to 1.4 microns. Input light is chopped at 13 cps. The chopper shaft carries a cam which operates a SPDT micro-switch at the same frequency. This permits use of a lead sulfide (Eastman Kodak Co. Type N-1 Ektron Detector, sensitive area: 2 x 2 mm.) detector feeding into the amplifier and recorder borrowed from a Perkin-Elmer infrared monochromator. This arrangement also provides for continuously recording a spectrum by driving the wavelength drum of the B & L Monochromator with a clock motor. The sample-in-sample-out method gives highly repeatable results. The continuous recording gives a spread of about 5 percent in successive recordings.

The curves shown in Figure 7 are the spectral transmission, relative to air, of two evaporated films of indium doped cadmium sulfide on glass substrates. Curve A is for an unprocessed film about 0.0025 cm thick. The absorption edge is not nearly so well defined as in single crystal samples. Curve B is the transmission of a film identical to that of Curve A (the films were evaporated simultaneously and are adjacent parts of the same substrate) except that it was processed by painting with precipitated cuprous oxide, heated in air at 300°C for a few seconds after which the excess oxide was brushed off. It will be interesting to compare the curves of Figure 7 with those of conventionally processed films and crystals, as well as unprocessed crystals. These measurements will be performed in the next reporting period.

The curves in Figure 8 are the spectral transmission, relative to air, of four samples of duPont H-film. Curve A was obtained from a single thickness of H-film, 0.0062 cm thick. This film has a yellow color similar to that of CdS. Curve B was obtained from a triple thickness of the same H-film. Curve C is the transmission of a single thickness of H-film, 0.0118 cm thick. This film has a red-orange color, much darker than the thinner H-film. Curve D is a triple thickness of the latter film. It is interesting to note the somewhat greater transparency of the darker film in the near infrared region of the spectrum.

Comparing Figures 7 and 8, one may conclude that either of the H-films, in single thicknesses, may be employed as substrates for CdS cells, but the light colored film is far more preferable as far as spectral transmission is concerned.

Radiation damage by electrons, gamma rays and neutrons, to duPont's H-film was discussed in earlier reports. An experiment is underway at the present time to determine the effect of ultraviolet radiation on H-film. The samples are exposed to a mercury arc and shielded by a Corning 7-59 filter passing 0.30 to 0.48 micron radiation. This cuts off the strong 2530 Å line of mercury as well as approximating the short wavelength limit of solar radiation. The samples have been exposed for several hours to an ultraviolet intensity comparable to direct sunlight without visible effect. After a sufficient time, their spectral transmission will be remeasured and then the samples will be exposed to the unfiltered mercury arc.

#### 5. ALTERNATE METHODS OF PRODUCING FILMS

The "wet chemistry" approach to depositing thin films of CdS is continuing. Principal difficulty at the present time is adhesion of film to substrate. A two component spray is going to be tried shortly.

#### 6. PLANS FOR NEXT MONTH

The work described in this report will be continued. It is planned to initiate film structure studies.

#### 7. PERSONNEL

Time devoted to this project by principal technical personnel and others during the month of January follows:

<u>PERSONNEL</u>	<u>HOURS</u>
W. J. Deshotels	168
F. A. Augustine	176
A. E. Carlson	9
M. P. Makowski	141
Others	415
Total	<u>909</u>

8 EXPENDITURES

Actual Costs to December 31, 1962	\$27,300.00.*
Estimated Costs for January, 1963	\$ 9,000.00.

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\* This figure includes commitments to other Clevite divisions of approximately \$6,000.00 for scientific services to be rendered during the next 3 to 4 months.

9. DISTRIBUTION

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- VOLTS  
 JAN. 29, 1963  
 SINGLE CRYSTAL CELL #1 CDS(A-29)  
 PET. CO<sub>2</sub>O COATED WITH BRUSH  
 AREA = 3.84 CM<sup>2</sup>  
 $V_{oc} = 0.52V$   
 $I_{sc} = 18 \text{ MA}$   
 $V_{mp} = 0.34V$   
 $I_{mp} = 13.5 \text{ MA}$   
 ILLUMINATION = 100 MW/CM<sup>2</sup>  
 EFF. = 5.47%

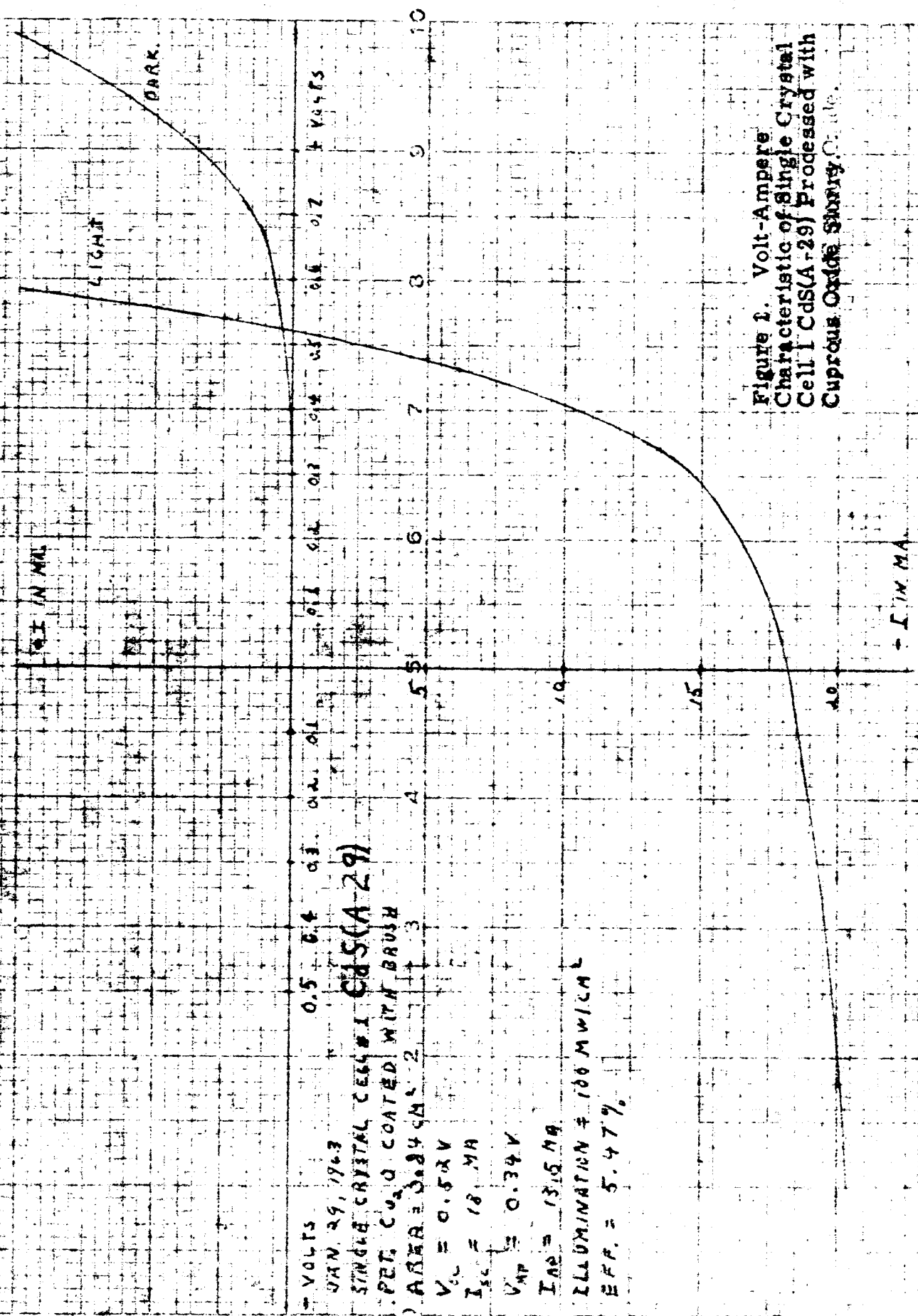


Figure 2. Volt-Ampere  
 Characteristic of Single Crystal  
 Cell 1 Cds(A-29) Processed with  
 Cuprous Oxide Slurry.

- VOLTS  
 P.V.  $\text{Cd}_2\text{O}$  POWDER CELL #3  $\text{CdS(A-29)}$   
 SINGLE CRYSTAL  $\text{CdS}$   
 AREA =  $1.7 \text{ cm}^2$   
 ILLUMINATION = 100 MW/CM<sup>2</sup>  
 $V_{OC} = 0.38 \text{ V}$   
 $I_{SC} = 38.0 \text{ MA}$   
 $V_{OC} = 0.55 \text{ V}$   
 $I_{SC} = 44.4 \text{ MA}$   
 $\eta_{EFF} = 7.02 \%$   
 JAN 30, 1963

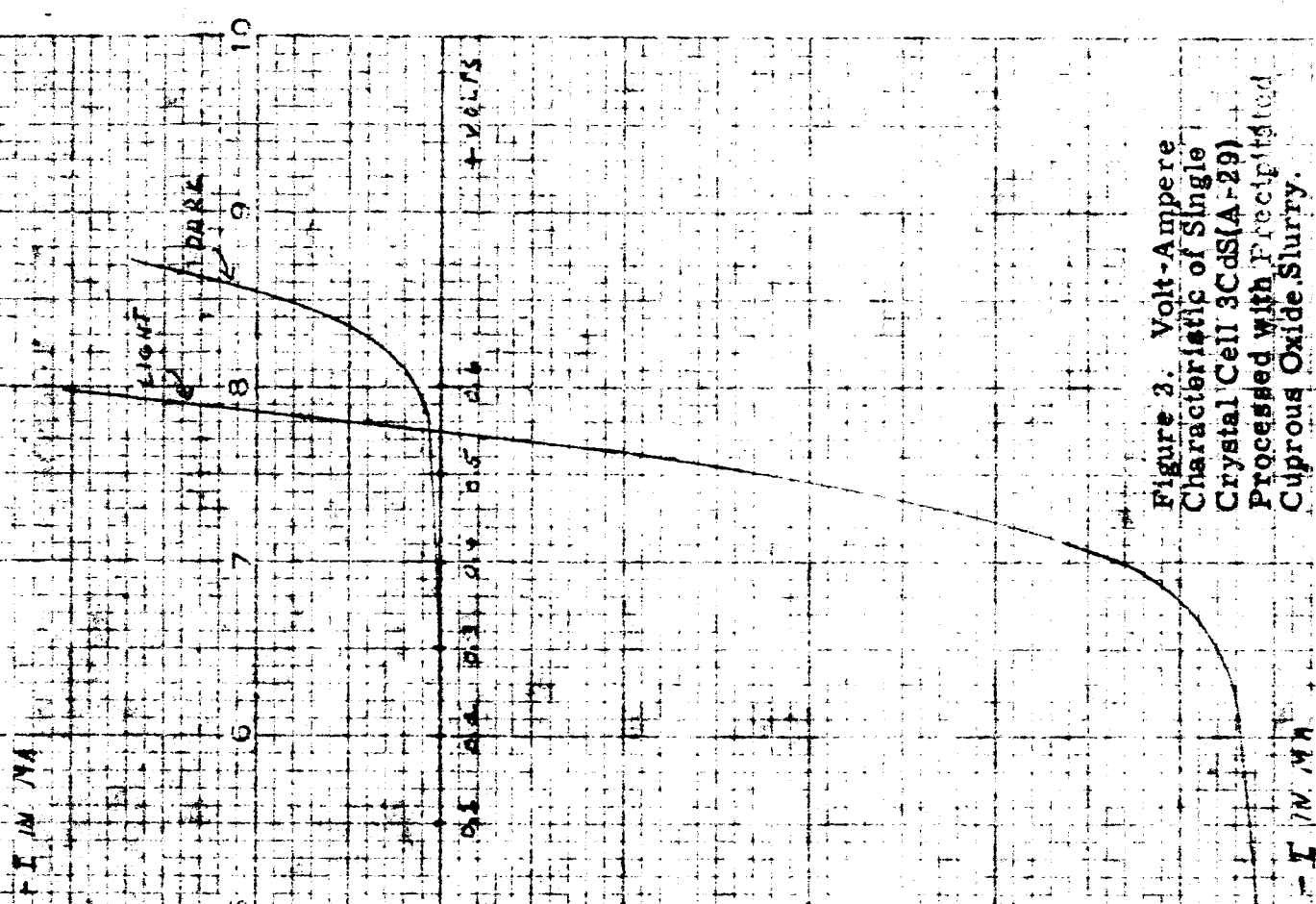


Figure 3. Volt-Ampere  
 Characteristic of Single  
 Crystal Cell 3CdS(A-29)  
 Processed with Precipitated  
 Cuprous Oxide Slurry.



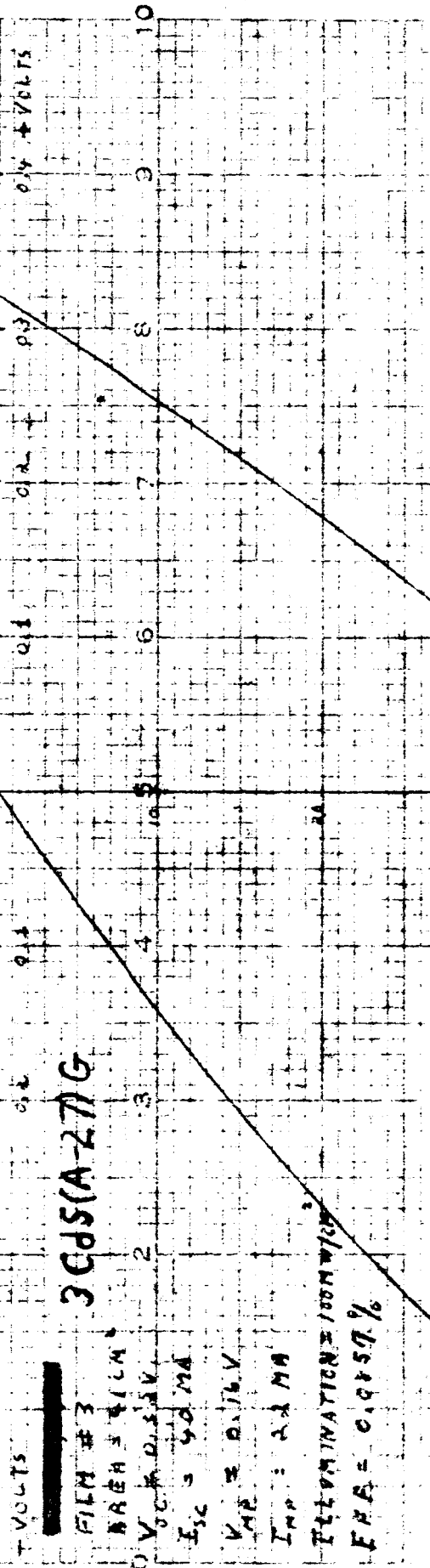


Figure 8. Volt-Ampere  
 Characteristic of Evaporated  
 Film Cell 3CDS(A-27) G  
 Processed with Precipitated  
 Cuprous Oxide Slurry

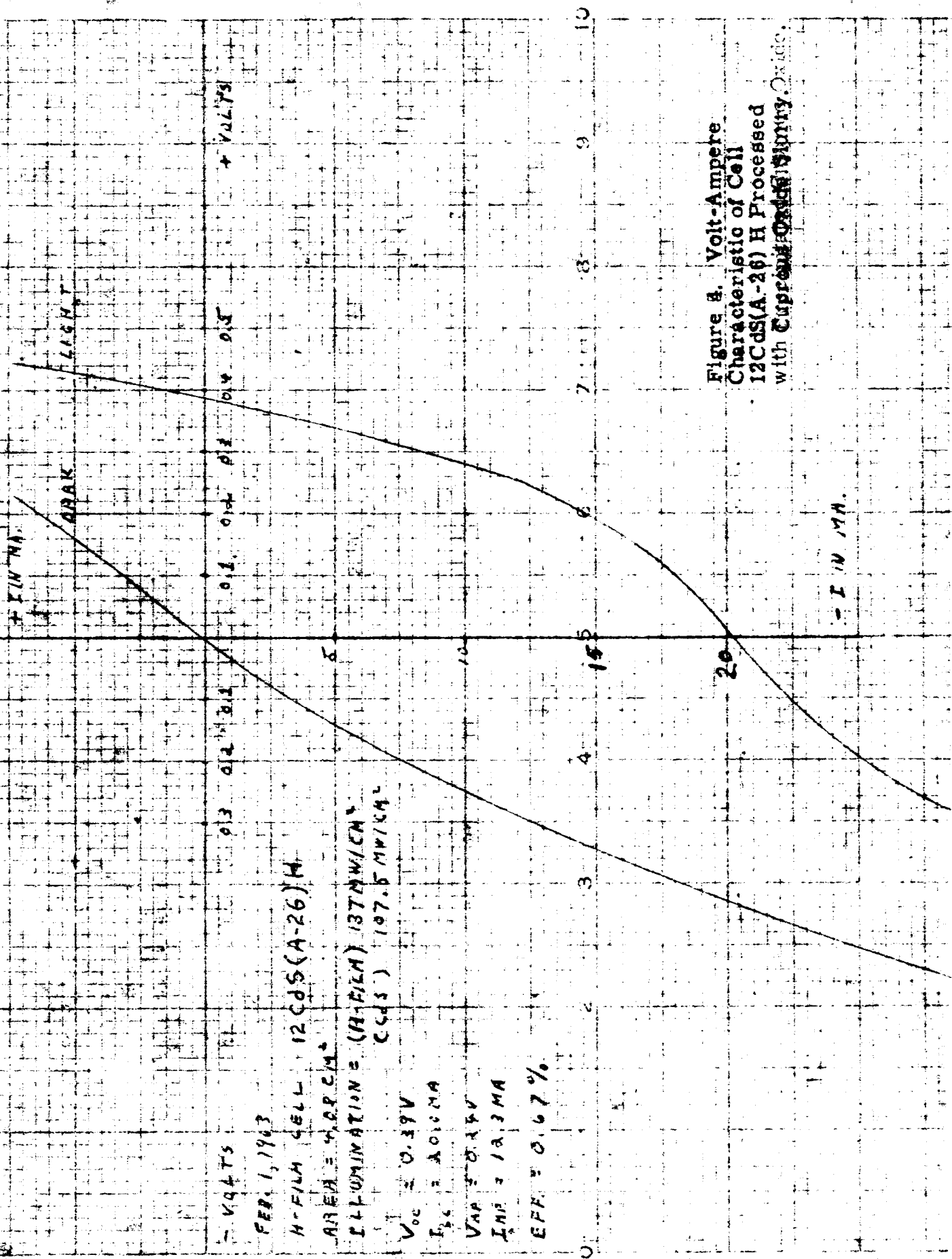


Figure 4. Volt-Ampere  
 Characteristic of Cell  
 12CDS(A-26) H Processed  
 with Cuprous Oxide in Nitric Oxide.

- VOLTS  
 JAN 24, 1963  
 FILM CELL ON GLASS -  
 AREA = 4.45 CM<sup>2</sup>  
 PPT. S<sub>2</sub>O<sub>3</sub> APPLIED WITH BRUSH  
 V<sub>OC</sub> = 0.337V  
 I<sub>SC</sub> = 36 MA  
 V<sub>MP</sub> = 0.188V  
 I<sub>MP</sub> = 21.0 MA  
 ILLUMINATION = 100 MW/CM<sup>2</sup>  
 EFF. = 0.89%

12b-CdS(A-26)G

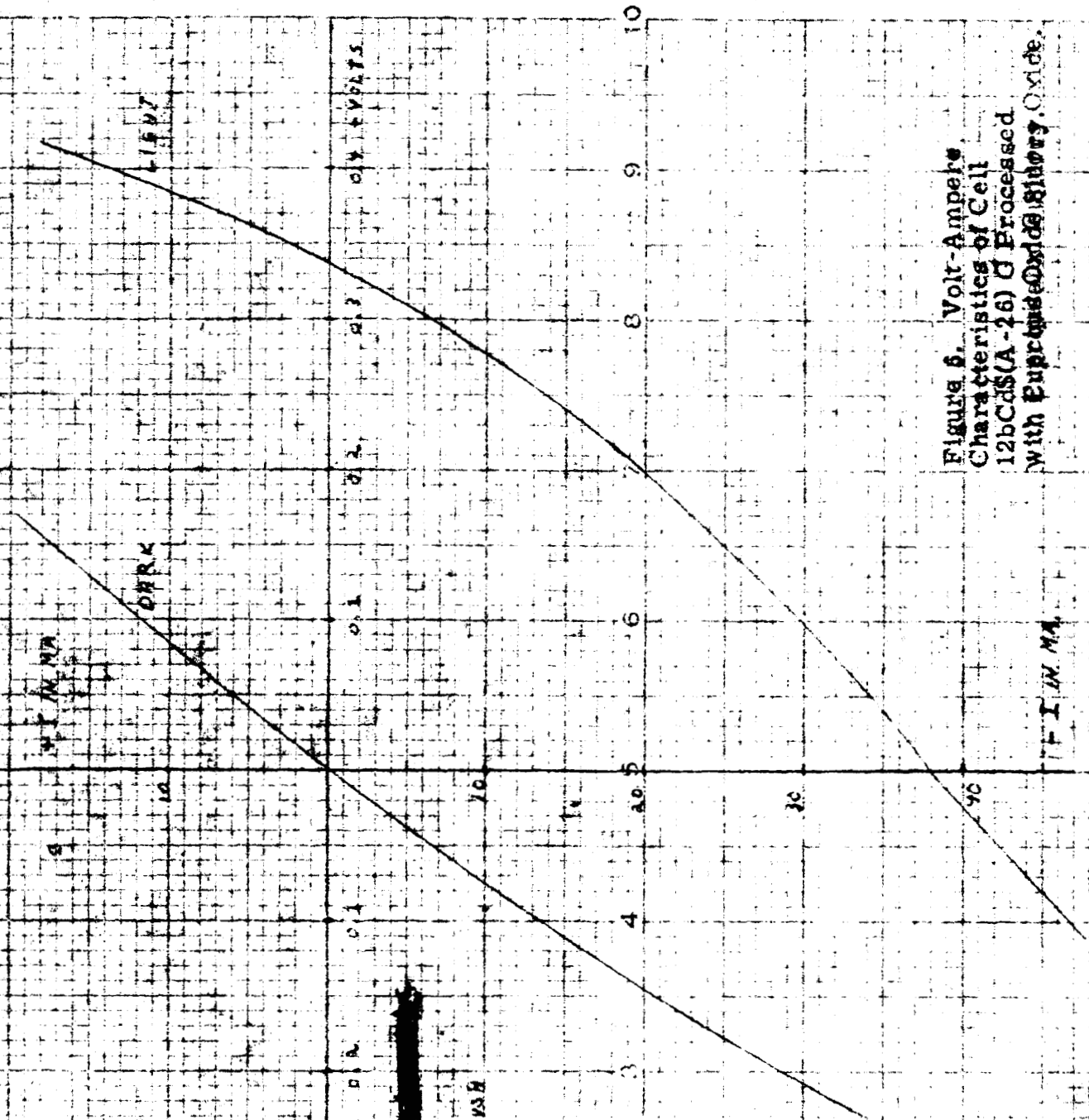


Figure 6. Volt-Ampere  
 Characteristics of Cell  
 12bCdS(A-26) G Processed  
 with Euphrase Oxide Slurry Oxide.

- VOLTS  
 JAN 7, 1963  
 FILM SECH ON GLASS  
 $V_{MP} = 0.345V$   
 $I_{MP} = 5.8 MA$   
 $AREA = 0.44 CM^2$   
 $ILL = 100 MW/CM^2$   
 $V_{OC} = 0.348V$   
 $I_{SC} = 8.8 MA$   
 $EFF = 3.23\%$

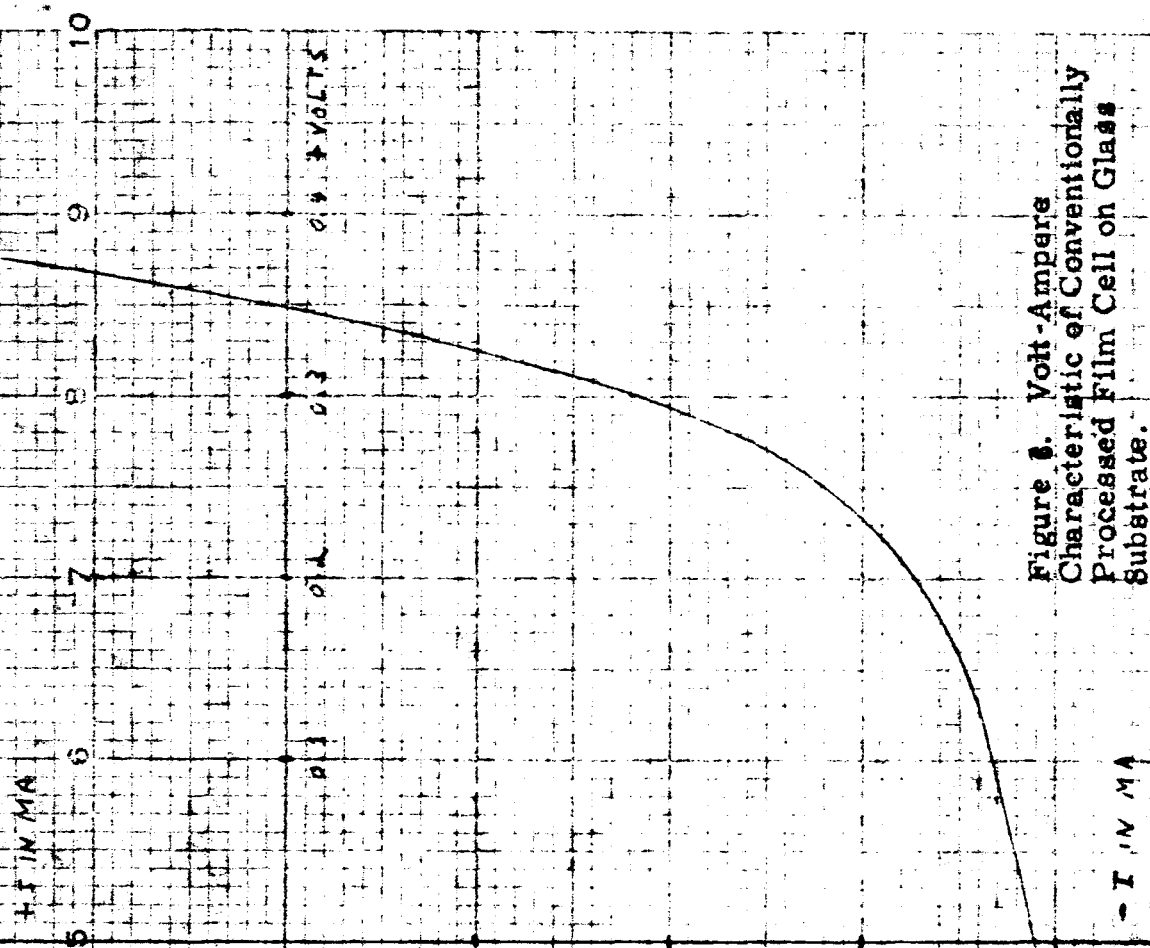
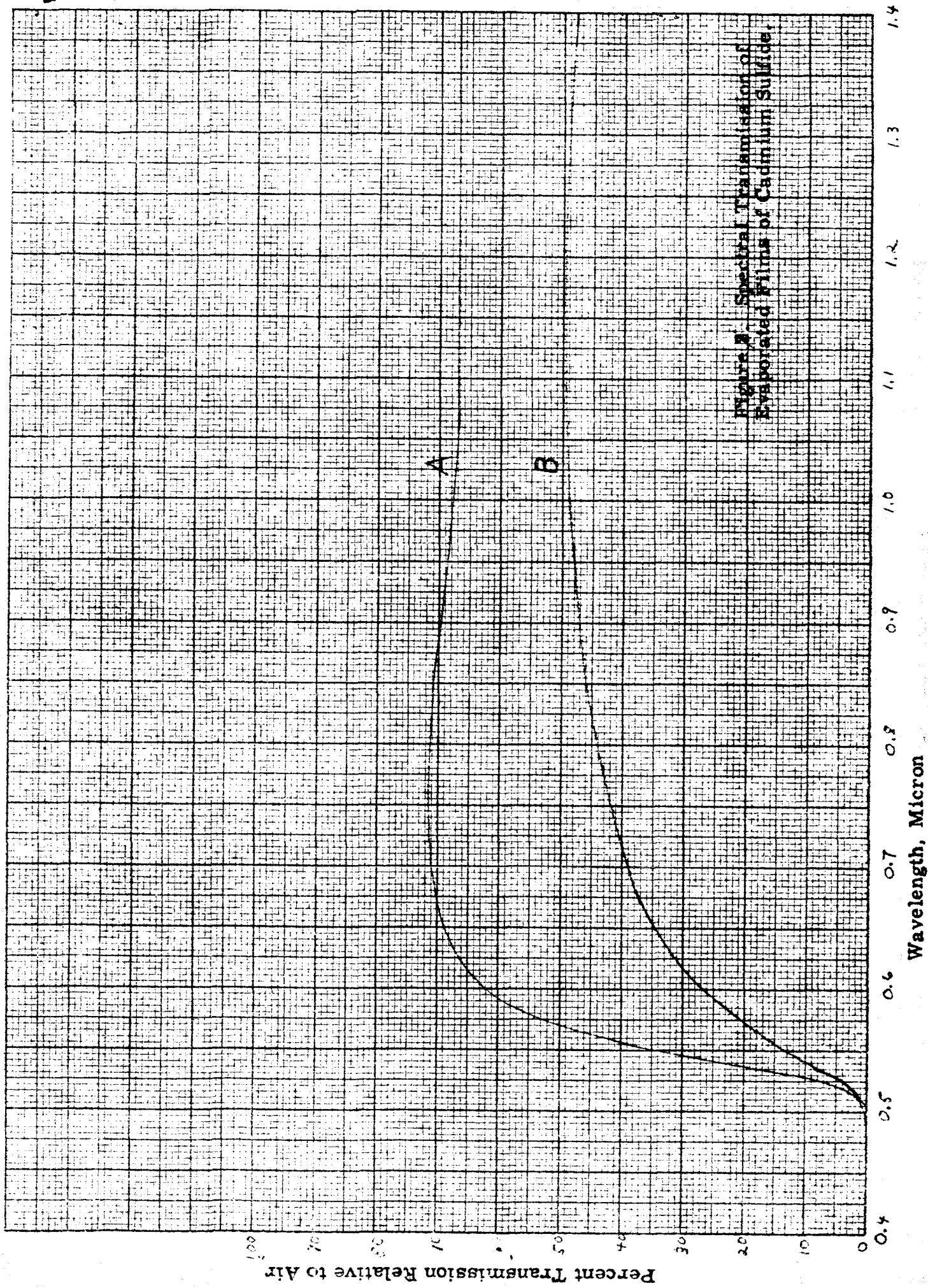


Figure 3. Volt-Ampere  
 Characteristic of Conventionally  
 Processed Film Cell on Glass  
 Substrate.





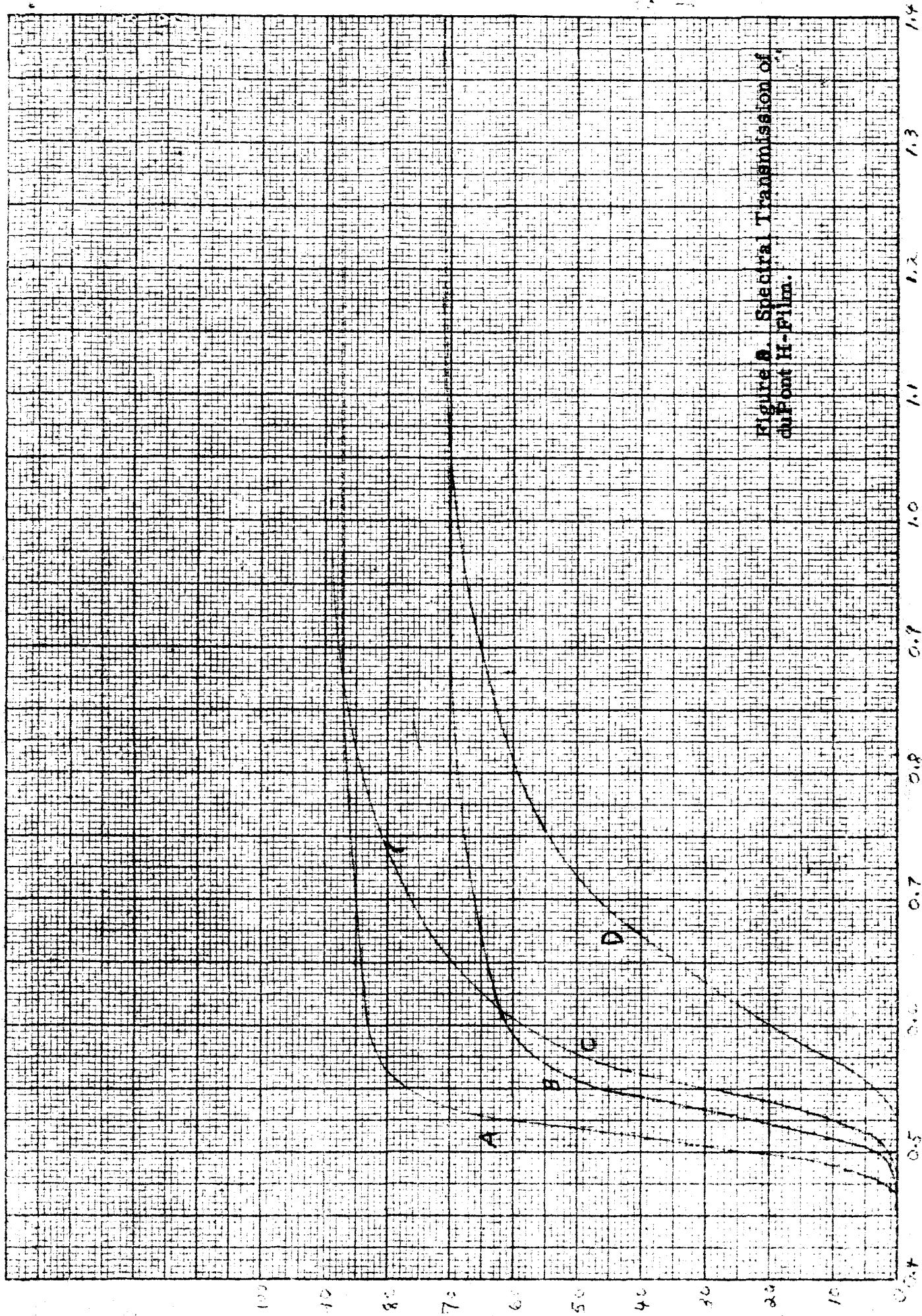


Figure 8. Spectral Transmission of du Pont H-Film.

Wavelength, Micron